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V.I. Teleshev and S.A. Frid

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COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
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This report discusses the principal aspects of designing concrete dams on rock foundations in regions with especially harsh climates, developed by examining projects carried out at Lengidroproyekt.

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The present collection contains articles by associates of the Leningrad Branch of the "GIDROPROYeKT" Institute imeni S. Ya. Zhuk, dedicated to the planning and construction of hydraulic facilities on the Zey River.

V. N. Vagner, V. I. Teleshev. Solid Multiple-Arch Dam at the Zeysk Hydroelectric Power Station.

V. I. Teleshev, V. I. Khelevin. Method of Calculating the Stressed State of the Multiple-Arch Dam at the Zeysk Hydroelectric Power Station.

V. I. Teleshev, S. A. Frid. Planning Concrete Dams for Particularly Harsh Climatic Conditions.

DESIGNING CONCRETE DAMS FOR ESPECIALLY HARSH CLIMATIC CONDITIONS

V. I. Teleshev, S. A. Frid

During the last 20 years, extensive hydraulic engineering construction projects have advanced far into the depths of regions of our country with harsh and very harsh climates. Exploitation of the very rich energy resources of the rivers in the central and eastern parts of Siberia, the coastal regions, and the Far North has posed a number of complex problems for designers and builders of hydraulic engineering projects which they had not encountered before.

In the early 1960s the Lengidroproyekt office built the Mamakansk Dam in the Bodaybo region, on a tributary of the Lena River, and is now building the dam for the Zeysk Hydroelectric Power Station on the Zey River. The sites of these dams are characterized by a very harsh climate, with an average air temperature of -4 to -6°C and variations of about 50° in the average monthly temperature. The sites of the Krasnoyarsk and Bratsk Hydroelectric Power Stations are also characterized by particularly harsh conditions.

The experience gained in planning and building these dams and in constructing the Sayano-Shushensk and Ust'-Ilimsk hydroelectric power stations under similar conditions forced Soviet hydraulic engineers to make pioneering efforts at organization of equipment testing and planning in places where such factors as temperature effects, the presence of permafrost, a short positive temperature period, and the prolonged cold of winter must be taken into account.

It should be kept in mind that tradition, experience in designing concrete dams on a solid foundation, the general level of design calculation for structures, and in particular the specific operating conditions in regions with very harsh climates have led specialists involved in planning to use different approaches to the design of these structures and have established the basic principles for organization and accomplishment of the work.

In the following, we shall discuss the principal aspects of designing concrete dams on rock foundations in regions with especially harsh climates, developed by examining projects carried out at Lengidroproyekt.

General Considerations

Initial efforts at designing concrete dams for the Krasnoyarsk and Mamakansk Hydroelectric Power Stations (1956-1961) revealed the need for a detailed and comprehensive study of air temperature variations as the principal factor determining the strength and service life of structures, construction conditions, operation of hydroelectric power stations, and other parameters.

The need arose to develop and select optimal structural solutions for dams, most appropriate for implementation and use in harsh and particularly harsh climates.

In this connection, it was necessary first of all to devise methods and means of detailed analysis of the temperature regime of structures and their foundations under conditions of laying concrete during construction, and then during operation.

Prior to 1965, these calculations were performed by numerical and graphoanalytical methods without using computers. Later, a special computer program, the BKT-M was written and could be used to develop a practically convenient algorithm for solving relationships in the theory of nonstationary thermal conductivity of solids.

The writing of this universal program created a similar analysis of temperature fields as a necessary element of structural design.

To establish the boundary conditions, the problem of the formation of the temperature regime in reservoirs which, together with the air temperature, also determines the temperature field of dams under operating conditions had to be considered. Critical analysis of theoretical solutions and observational data on existing bodies of water made it possible to obtain a sufficiently reliable basis to predict this very important structural operating condition.

An important element of the planning operation was the investigation and determination of the physical and mechanical characteristics of concrete and the development of requirements to determine its quality, and thus ensure long service life under harsh climatic conditions.

By means of special studies organized at the laboratories of LIIZhT, VNIIG, and LTIKhP, as well as directly on the structures of the Krasnoyarsk Hydroelectric Power Station,

thermophysical characteristics were investigated, including such properties of concrete as its ultimate extensibility.

All of these studies showed a need, in many cases, to specify the brand of concrete for dams (especially in the interior) to ensure the necessary value for the ultimate extensibility ε_{lim}. The establishment of a relationship between ultimate extensibility of concrete and its stressed state and in particular on the stress gradient $\varepsilon_{lim} = f(\partial\sigma/\partial n)$ was very interesting.

It was found that for considerable stress gradients, characteristic of temperature effects, the ultimate extensibility of concrete increases markedly, which explains the ability of concrete to retain its crack resistance in the face of relatively great changes in ambient temperature and in the temperature of the concrete itself [3].

Determination of the thermophysical properties of concrete and rock foundations also played an important role in ensuring the reliability of the design basis for the structures. Thermal conductivity and thermal capacity of concrete as a function of temperature were determined [1].

Considerable difficulty was encountered in establishing such important basic data as the release of heat in the concrete, which governs the temperature regime of concrete during the first few days after the mix is poured.

Correct evaluation of this phenomenon solves many problems involved in combatting early crack formation. However, in many cases the release of heat which takes place under laboratory conditions does not correspond to the temperature rise under field conditions. This lack of correspondence sometimes misleads designers.

At the present time, the most reliable method of acquiring mathematical data on the adiabatic temperature rise in concrete is apparently a reverse calculation of this factor on the basis of data from observation of the temperature of concrete blocks.

At preliminary stages, this characteristic must be determined by analogy, then made more precise on the basis of data from observation of the first blocks of concrete which are laid.

This approach cannot be considered completely normal, but experience from observations during construction of the Chirkeysk,

Zeysk, and Sayano-Shushensk hydroelectric power stations indicates the necessity of recommending this practical approach until a reliable method is worked out to determine concrete characteristics by a laboratory method.

The problem of regulating the temperature regime in concrete which has been poured required development of a theory and practical method of calculation. Reliable solutions were obtained which made it possible to take into account the influence of cooling concrete using pipes [2]. A method was established to estimate cooling of a concrete mix, changes in temperature of the mix during transportation and while pouring it, determination of the permissible setting rate, and so on. All of these calculations are now routine and necessary in planning dams at Lengidroproyekt.

Mention should be made of the considerable role played by the engineering approach developed at Lengidroproyekt for the Krasnoyarsk Hydroelectric Power Station dam, in regard to regulation of the temperature of the concrete used for protection against crack formation and subsequent solidification of the body of the dam, by means of cementing.

We could mention the determination of the value for the optimum interval for laying the cooling pipes, which is 1.5 x 1.5 or 1.5 x 3.0 m, as well as the initial data obtained on the strength of the vertical structural seams into which cement was poured. It was found that to break these seams, the concrete had to be cooled to 8-10°; it was only after this, as the seams were setting, that values were reached which were dictated by the technology of cementation work.

Construction experience showed that a reliable correlation between the technology involved in working with concrete and the planning requirements, like the relationship between builders and designers, can only be achieved with a sufficiently detailed and carefully worked-out set of engineering rules for concrete work, as a special section of the project. The preparation of a document of this kind at the technical planning stage and its improvement at the working drawing stage, along with agreement with the builder, became necessary when planning large concrete dams, especially in harsh climates.

Field observations revealed that in designing concrete dams for a harsh climate it is necessary first of all to take into account the possible opening up of the structural seams along their lower limits, leading to a decrease in the working cross section of the dam. Calculation showed that for ordinary

solid gravity dams with a solid profile, such cracks could be 4 to 6 m deep, corresponding to an 8 to 12% decrease in the computed cross section of a dam 100 m high. This can cause considerable deterioration of the stressed state of the dam, especially at the upper limit.

The second important problem in planning dams for these conditions is the considerable likelihood that vertical intercolumnar seams will open up as the concrete sets at low operating temperatures, creating a stressed state in the dam which is less than the specified value and is difficult to adjust to the latter.

The problem of reliable solidification of the seams of a dam under the conditions of an especially harsh climate is one of the critical factors which determine its operating characteristics and service life [6].

The next problem involved in the planning of dams has to do with the provision of reliable drainage for the foundation and stability of the counterpressure epura in the foundation.

The solution of this problem is particularly complicated when permafrost lenses are present; construction of the cement curtain is then shifted to the period after the foundation thaws under the influence of the filling reservoir.

In the following, using specific examples, the principles involved in calculating these planning requirements are discussed. It has been found that for wide sections, it is necessary to deviate from ordinary solid gravity dam structures and to use lighter designs which resemble the multiple-arch type, and (within rather narrow limits) it is necessary to employ specific features of arch dams, which allow sufficiently reliable and economic planning for the most difficult climatic conditions.

Planning the Dam at the Mamakansk Hydroelectric Power Station

The Mamakansk Hydroelectric Power Station is located in a permafrost zone. The climate in this region is harsh, sharply continental, with air temperatures varying 97°. The average air temperature is -5.8°. The temperature in January (the coldest month), falls to -60°C, while in the warmest month (July) the temperature rises to +37°C.

A gravity dam of light construction was built in this region, with closed air spaces, satisfying the requirements for

ensuring solidity and reliability of operation of the equipment in such harsh conditions while saving concrete by comparison with a solid dam [4].

The dam has a slope at the crest of 1:0.05 and 1:0.75 at the foot. The maximum height of the dam is 57.0 m; the length of the crest is 345.0 m; the maximum width at the base is 43.0 m (Figure 1).

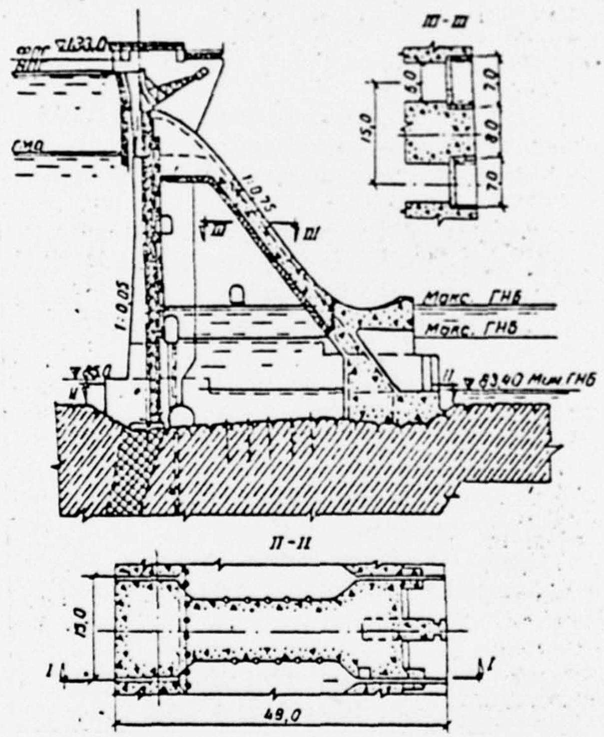

Figure 1. Cross Section Through Mamakansk Dam.

The dam is divided by temperature seams into 23 sections, each 14.5 to 15.0 m long. The width of the internal cavities of the dam is 6.0 m.

For a better understanding of the sharp changes in temperature in all parts subject to the action of outside air, additional

seams or notches were made, dividing a section 15.0 m wide into sections each 7.5 m wide (in a solid dam), or 6 and 9 m wide (in a spillway dam).

On a stationary part of the dam, the upper and lower supporting walls of the water intake above the reservoir storage level were cut from the buttresses and act independently when temperature deformation occurs.

The covering of the expansion seams at the foot of the dam was cut away from the arches and supported freely on them. The horizontal sliding seams were also constructed on the support of the dam.

These computations showed that for the conditions at the Mamakansk Hydroelectric Power Station, a solid dam without closed spaces and artificial heating of the latter would freeze more than half of the profile, up to a zone immediately adjacent to the supporting edge.

The danger of freezing of the drainage system in the body and foundation of the dam, which could lead to a sharp increase in the counterpressure, and consequently to a decrease in stability, was very real.

In the stationary part of the dam, water freezing at the contact between the metal pipe and the concrete could result in deformation of the pipe. To prevent these phenomena in the dam, special closed spaces (expansion joints) were provided where the temperature could be artificially maintained between 0 and +5°, ensuring an optimum temperature regime within the body of the dam. The basic mass of concrete has a constant positive temperature and the influence of varying temperature is felt only in a limited part of the lower edge of the dam, where it is 2 to 3 meters thick.

To ensure that the concrete covering is crack-resistant and that the structure is solid, a section was prepared on columnar blocks of concrete, with maximum horizontal dimensions of 15 x 12 m and 4 meters high.

In contrast to the method of in situ casting of a dam as usually employed, with columnar construction by cementation of the intercolumnar seams, the system for in situ casting of the Mamakansk Dam provided for construction of voluminous intercolumnar seams 1.2 m wide, subsequently filled with concrete, reaching a weighted mean temperature for adjacent columns which did not exceed the temperature of the

body of the dam during the constant operation period (about 0°C).

The decision not to use the in situ casting method with columns was made because under such harsh climatic conditions it would have been impossible to ensure a positive temperature for the blocks as they set. Even in a heated enclosure in winter, the blocks froze completely within 2-3 months, depending on the temperature of the outside air. The inhomogeneity of distribution of the concrete temperature through the block reached 20-25°. The blocks thawed completely only at the beginning of August, when the surface temperature of the concrete reached 15-20° [4].

A combination of the spaces in the dam with in situ casting, by filling the voluminous intercolumnar seams in the dam with concrete, made it possible practically to eliminate artificial cooling of the concrete covering (with a few exceptions).

For closed blocks, specially prepared concrete was used which settled only slightly, with cement consumption amounting to 170 kg/m^3, with a conical slump of 0.1 to 0.5 cm.

Concreting the contact blocks in winter, with the concrete frozen completely through, was carried out after heating the concrete in the columns in a zone which was in contact with the voluminous seams, to a depth of 15-20 cm, or by heating only the surface and using electrical heating thereafter as the concrete set.

To ensure a stable temperature field for the basic dam structures during operation, electrical heating was provided for the air in the spaces, using electric heaters with a total power of 80 kW. The electric heaters were switched on only in late winter, for 1.0 to 1.5 months. Some years no electric heating was used.

In the mass of concrete during operation, a constant mode was established, with a concrete temperature of about 5° with the exception of zones along the lower limit, where the concrete was subject to variations in outside air temperature.

The equipment at the Mamakansk Hydroelectric Power Station has been operating since December 1961. In 1964 the dam accepted a full head. Observations of the condition of the dam showed normal operation of all parts and elements. Dam deformation has occurred at the limits of its elastic, monolithic operation. Observations of filtration in the structure showed that filtration (in the form of small drops) takes place only along

certain temperature seams. No filtration has been seen to occur through the concrete of the supporting edge, indicating that it is sufficiently impermeable to water.

The drainage and cement curtain at the base of the dam are operating normally. Counterpressure at the base of the dam, behind the drainage line, is practically nonexistent.

Planning the Dam at the Zeysk Hydroelectric Power Station

Further development and improvement in the design of dams for harsh climates is represented by the Zeysk Hydroelectric Power Station Dam.

The climatic conditions at the site of the Zeysk Hydroelectric Power Station resemble those at the Mamakansk Hydroelectric Power Station.

The average annual temperature is -4.1°. The extreme value of the temperature amplitude is 95.2°, while the amplitude of the average monthly temperature is 50.1°.

The dam is 115 m high, and the crest is 710 m long. The volume of concrete in the body of the dam is 2,200,000 m^3. The need to construct such a large dam under such harsh climatic conditions, working the year round, and with no experience in building and implementation, posed problems relating to the selection of the type of dam which were very complicated and difficult. Experience with construction and operation of a dam with expansion seams at the Bratsk Hydroelectric Power Station was analyzed [7]. The problem of cooling the concrete covering to a minimum temperature for casting (+4 to 5°) in proper time remained unsolved here; the time during which cement could be poured was reduced to 1.5 to 2 months a year.

The impossibility of carrying out reliable monolithization of the longitudinal intercolumnar seams of the Bratsk Dam meant that the stressed state was unsatisfactory at the most sensitive point on the upper edge, i.e., at its contact with the foundation. The foundation began to loosen in the vicinity of the contact between the cementation curtain and the foundation, and local filtration pressure increased with filtration. The curtain had to be renewed periodically at its root [8].

The situation could have turned out much more seriously if there had not been spaces in the dam in the temperature seams

between the sections, which determine the flexible local nature of the increase in counterpressure within the limits of the cap.

These factors determined the choice at the Zeysk Hydroelectric Power Station of a light design for the solid dam, with large closed spaces between the individual sections. The dam was called a solid multiple-arch dam, although there were a number of features that distinguished it considerably from known foreign designs of solid multiple-arch dams.

In planning the Zeysk Dam, it was decided to minimize the possibility of contamination of air spaces; the basic method used was the development of an industrial casing with a reliable heater (expanded plastic).

The dam was built as a multiple-arch structure with arches 7 and 5 meters thick and 15 meters wide in a typical section.

This design satisfied the basic requirements set forth above and made it possible to reduce construction cost 15% in comparison with a solid gravity dam.

In examining the gravity dam option, the possibility of heating the lower boundary of the dam was taken into account, using electrical heating and other measures intended to prevent considerable change in the temperature field in the structure and the opening up of structural cracks. However, all these measures failed to provide the necessary and economic solution.

The analysis of the behavior of the dam which was built, supported at the present time by three years' construction experience, showed the definite advantages of this design. The length of the period when concrete could be cast was 6 to 7 months instead of 1.5 to 2 months for contact-cemented seams; there was no need for definite correlation using a graph showing the behavior of adjacent columns as a function of temperature conditions; more than half of the volume of concrete turned out not to require cooling by pipes, making it possible to save more than 1200 tons of pipe, and so on.

In the project, the construction of the upper solid cap was simplified as much as possible (Figure 2), and the topmost limit was made as nearly vertical as possible. This feature of the structure, which differs considerably from known foreign examples, was based upon the results of a study of achievements in the field of mechanics of solid foundations

and a better understanding of the problem, ensuring stability of structures erected on these foundations.

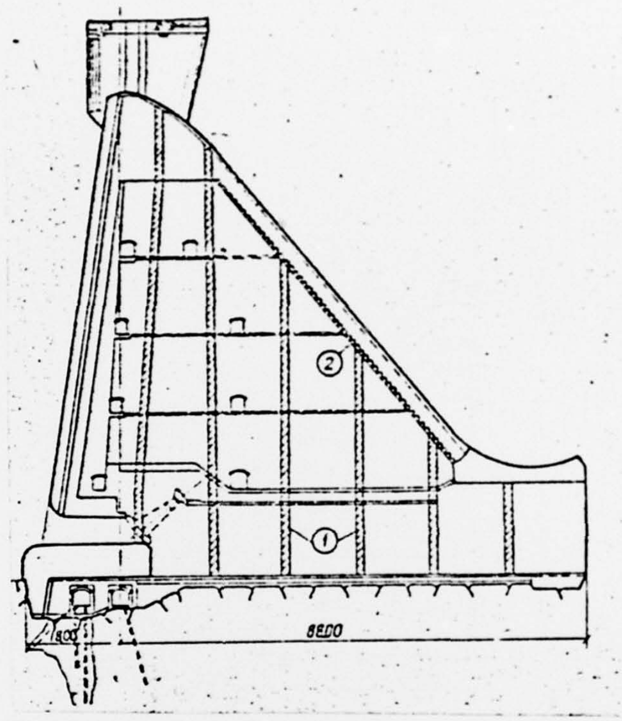

Figure 2. Cross Section through Zeysk Spillway Dam.

On the basis of the conditions for putting together the aggregate block, the station part of the dam required a special structural solution. It consisted of two arches each 5 meters thick, linked by a common cap. The width of the section of the stationary part of the dam was 24 meters. Experience in planning the Krasnoyarsk Hydroelectric Power Station had demonstrated the advisability of separating the pipe from the body of the dam, simplifying the assembly sequence and the construction of the body of the dam. Using this type of construction for the dam, it was not possible to achieve complete separation of the pipes; a sliding seam was therefore constructed between the lower wedge of the dam, containing pipes, and the arches. In this manner, the pipe cooperated with the other parts of the dam to ensure the strength and stability

of the structure, but its presence did not disturb the function of the arches of the dam (Figure 3).

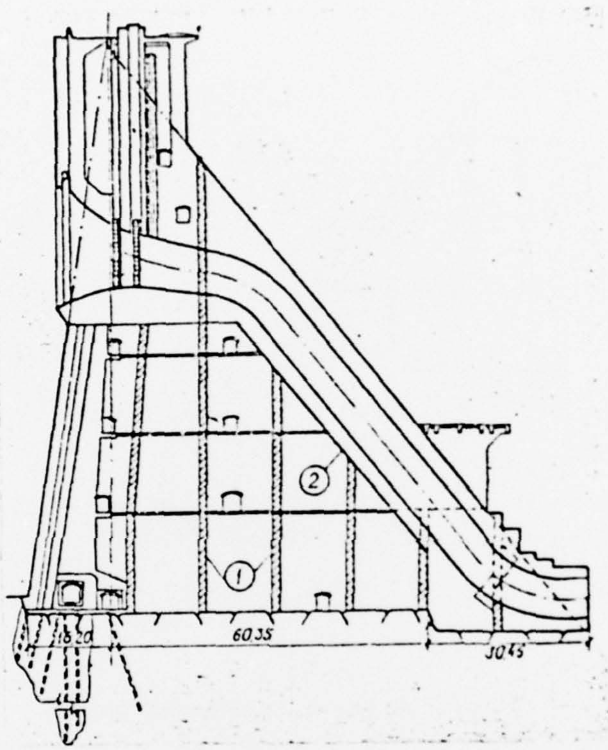

Figure 3. Cross Section through Zeysk Stationary Dam.

As in the Mamakansk Dam, the air spaces between the arches were covered with removable members, which were also used to cover the solid concrete. The thickness of the covering of the lower limit of the dam was based on calculations.

Experience in planning, building, and operating the Mamakansk Dam and in designing and building the Zeysk Dam, together with data from field observations, make it possible to recommend this type of construction for extremely harsh climatic conditions, using wide members which did not allow arch dams to be used.

Arch Dams

Planning arch dams for harsh climatic conditions is based upon experience in planning the arch-gravity dam (240 meters high) at the Sayano-Shushensk Hydroelectric Power Station and a type of arch dam 145 meters high for the Bureysk Hydroelectric Power Station.

The first of these dams was planned for conditions closely resembling those at the Krasnoyarsk Hydroelectric Power Station, while the other was built under conditions absolutely identical to those at the site of the Zeysk Hydroelectric Power Station, which are considered especially harsh.

The first question regarding these conditions relating to the opening up of structural seams along the lower limit was solved quite simply in both these situations. A properly planned arch dam is always characterized by rather high compressive stresses (up to 100 kg/cm^2) along much of the lower limit, which largely reduces the possibility and extent to which seams open up along the thickness of the dam. Because of the three-dimensional nature of the operation of these arch dams, seams may open up, not along the entire bottom of the dam, but along only part of it. For these reasons, the calculations of the stressed state of the arch dam at the Sayano-Shushensk Hydroelectric Power Station showed that the influence of the opening up of the seams changes the stresses at individual points by 2-3 kg/cm^2, with basic stresses on the order of 100 kg/cm^2.

A similar pattern was also observed in the relatively thin dam at the Bureysk Hydroelectric Power Station, where the of the seams changes the stressed state by no more than 5%. Hence, one of the principal problems specific to the operation of dams in particularly harsh climates can apparently be solved without difficulty.

It is more difficult to deal with the problem of costing radial seams. The basic type of construction used for radial seams of arch dams consists of contact cemented seams.

The cementation temperature of such seams can be assumed for all practical purposes to be at least +5 to 8°. Consequently. it is necessary to take into account the possibility that there will be considerable cooling of the concrete in the lower part of the dam (on the lower limit side). However, calculations have shown that the compressive stresses in the arch direction, for economically planned dams, usually amount to 60-80 kg/cm^2. This fact ensures reliable operation of the

seams over much of the arched zone over practically the entire thickness.

The possible opening up of radial seams in the Bureysk Dam to a depth of 2-3 meters, but no further, does not cause any unexpected changes in the stressed state in the profile of the dam which differ from those which occur as a result of the opening of horizontal structural seams.

The third problem had to do with the fact that in a thin arch dam it is possible for the body to freeze during construction throughout its thickness, dictating a comparatively short period during which cementation of radial seams can be carried out; indeed, under certain conditions cementation by ordinary methods is impossible.

This is admittedly the most difficult problem, but there are two ways of solving it.

In a portion of the profile of the dam, at the level of the upper arch, and sometimes at the level of the river bed, enclosed voluminous seams that can be filled with concrete may appear (Figure 4).

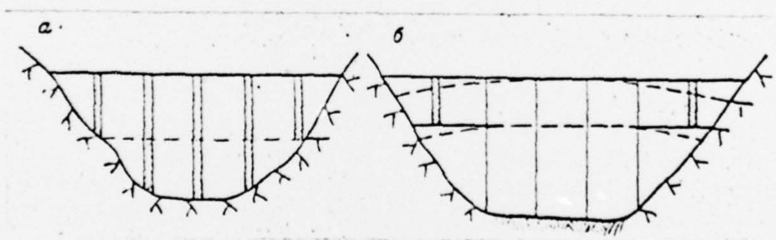

Figure 4. (a) Diagram of Arch Dam with Possible Location of Seams. (b) Diagram of Arch Dam with "Plunging Arches" and Voluminous Seams in Upper Arch.

The use of such designs for the seams is facilitated to some degree by the specific features of modern arch dams; when the dam is less than 30 m thick there is no need to organize the intercolumnar longitudinal seams. This sharply reduces the volume of concreted seams and increases the strength of the freely standing columns. When the width of the voluminous

seams is 2-2.5 meters, concrete can be poured normally into the central part of the seam.

The second method of ensuring solid construction of a dam when its profile freezes throughout its entire thickness consists in organizing a repeated cementation system which, in the case of arch dams, is nearly obligatory.

It is suggested that primary cementation be carried out at a positive concrete temperature during initial setting, and that secondary cementation occur immediately after the beginning of the filling of the reservoir in June and July, when part of the profile of the dam (at the boundary) has already been heated. In this case, secondary cementation obviously will be of the keyed expansion joint variety, in other words, it will be carried out at those points where contact has been broken after primary cementation. It will then consist only in repeated filling of the seams in the central part of the body of the dam. Experiments in cementation of the seams of the Bratsk Dam by the so-called "cold solution" method indicate that further improvements in cementation technology using this solution will make secondary cementation reliable.

Finally, the preparation of a cementation network in the radial seams of the dam is bound to be more complicated than usual, with crushing of the drainage channels not only along the top but through the thickness, depending upon temperature distribution.

Finally, there remains the important question of the role of the change in average concrete temperature during operation of the dam and taking it into account in estimating the strength of the latter. Experience in dam calculations at the Sayansk Hydroelectric Power Station, performed by various methods, including the method of finite elements (three-dimensional problem) has shown that problems arise only in the upper arch, with a height on the order of 25 meters. This part of the dam is practically free of compressive stresses from hydrostatic loads, since the "plunging arches," characteristic of these dams, are formed. Under these conditions, with high computational temperature values and drops in the upper arch during settling, considerable expansive stresses develop which exceed the tensile strength of the concrete. Obviously, attempts to transfer these stresses to the armature will be only partially successful. Thus, the natural solution might be to construct in the upper part of the dam a voluminous seam, filled with concrete at the end of the winter at a negative concrete temperature. In this case, it

would be possible to eliminate not only the negative effects of temperature upon the stressed state of the dam, but to produce a certain positive effect, i.e., compression of the upper arch.

These considerations indicate that an appropriate study of the situation can solve all of the complex problems of planning arch dams suitable for normal operation under the most severe climatic conditions.

Features of the Design Basis of the Dam

It follows from the above that the primary factor in the basic design of concrete dams for harsh climatic conditions is a detailed investigation of the temperature field of the structure under operating and construction conditions. A study of the temperature field is especially important in building thin arch dams.

In designing dams with large cavities, like the Zeysk Dam, the first step in studying the temperature field involves determination of the required thickness for the covering at the lower boundary of the dam to resist cracking of the arches. If we know the thickness of this covering, we can then determine the temperature regime of the air in the cavity.

The methods for further calculation of the concrete temperature are governed by the means used (the type of computer program or the type of integrator).

After establishing the temperature regime for the equipment, a stage follows in which the depth of the covering of the structural seams at the lower limit is determined. For the conditions of a plane problem at Lengidroproyekt, a practical method was developed for performing these calculations by successive approximation [6].

In the case of a three-dimensional problem in arch dams, calculations should also be carried out using the method of successive approximation, with successive application of the stressed state due to external forces and the temperature stresses arising at the lower limit during setting. The technique employed in these calculations still remains to be worked out as it applies to various computational programs for arch dams.

The calculations that have been carried out indicate that the seams along the lower limit of an arch dam open 2-2.5 times

less than in a gravity dam. Hence, opening of the seams along the lower limit of an arch dam has practically no influence on the stressed state at the upper limit.

In view of the critical role played by temperature effects under these conditions, we must keep in mind the specific requirements for the method of static calculation. Specifically, these consist in the following:

In estimating the strength of the individual elements or parts of the structure, it is necessary to take into account the so-called "intrinsic temperature stresses" in the elements and structures, constituting beams and walls, i.e., thick structures which cannot be represented by rods.

The intrinsic stresses in such structures can be determined only on the basis of a solution of the thermoelasticity problem.

At the present time, the method of finite elements is widely used for this purpose; this indicates that estimation of the stressed state which arises from other stresses in structures must also be carried out by methods of elasticity theory, optimally on the basis of the same programs.

Significant problems also arise in determining the reinforcement for structures. Experience has shown that the use of ordinary strength criteria for calculating temperature effects, as indicated in existing standards, results in an unjustifiable over-use of metal.

Hence, Lengidroproyekt has devised a special method to determine the nature of the rebars in cases under study, based upon criteria used in estimating crack resistance of concrete coverings, i.e., based upon the tensile limit of the concrete.

Modern computer technology, now available to designers, along with much more powerful computers and an ever-expanding supply of programs make it possible to perform the required calculations at the necessary level within the time frame.

Finally, planning dams for especially harsh climates generally requires more computer power than for average and favorable climatic conditions; this must be kept in mind when organizing the design of such dams.

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